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Author(s): Zhenhua Luo , Bingwan Liu , Songtao Liu , Zhigang Jiang and Richard S. Halbrook

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Influences of Human and Livestock Density on Winter Habitat Selection of Mongolian Gazelle (*Procapra gutturosa*)

Zhenhua Luo^{1,2,3}, Bingwan Liu^{1*}, Songtao Liu⁴,
Zhigang Jiang², and Richard S. Halbrook⁵

¹College of Wildlife Resources, Northeast Forestry University, Harbin 150040, China

²Key Laboratory of Animal Ecology and Conservation Biology, Institute of Zoology, Chinese Academy of Sciences, Beijing 100101, China

³College of Life Sciences, Central China Normal University, Wuhan 430079, China

⁴Dalai Lake National Nature Reserve, Hulunbeir 021008, China

⁵Cooperative Wildlife Research Laboratory and Department of Zoology, Southern Illinois University, Carbondale 62901-6504, USA

Human and livestock related disturbances of habitat selection by ungulates are topics of global concern, as they have profound impacts on ungulate survival, population density, fitness, and management; however, differences in ungulate habitat use under different human and livestock densities are not fully understood. Mongolian gazelle (*Procapra gutturosa*), an endemic ungulate species on the Asia-European steppe, faces varying intensities of human and livestock disturbances in the area around Dalai Lake, China. To investigate how habitat selection strategies vary as disturbance intensity changes, we randomly set 20 transects containing 1486 plots, on which we conducted repeated surveys of 21 ecological factors during the winters in the period of 2005–2008. We aimed to: 1) determine the critical factors underlying habitat selection of the gazelles; 2) determine the gazelles' habitat preferences in this area; 3) determine how habitat selection varies with disturbance intensity and explore the primary underlying mechanism. We used binary-logistic regressions and information theoretic approaches to build best-fit habitat selection models, and calculated resource selection functions. Sixty-six herds, 522 individuals, and 499 tracks were recorded. Our results indicate that snow depth and aboveground biomass are the main factors affecting habitat selection by Mongolian gazelle throughout the district in winter. Thin snow cover and abundant aboveground biomass are preferred. Avoiding disturbance was the primary factor accounting for habitat selection in low disturbance areas, although with increasing human or livestock-related disturbance, gazelle maintained a reduced distance to the source of the disturbance. Presumably owing to that shift, movement costs were more important as disturbance increased. In addition, Mongolian gazelle selected habitats based on topographical features promoting greater visibility where disturbance was lower. We suggest several management implications of our findings for this ungulate species will contribute to the effective conservation of Mongolian gazelle in the Dalai Lake area.

Key words: Dalai Lake, habitat selection, human disturbance, information theoretic approach, Mongolian gazelle, *Procapra gutturosa*

INTRODUCTION

Habitat change has profound effects on habitat use, survival, population density, and the fitness of animals (Stuart et al., 2004). Slight changes in key ecological factors may alter the habitat selection strategy of wild animals (Johnson, 1980; Cain et al., 2008). Studying habitat requirements and determining the impacts of primary ecological factors and key resources on habitat selection may thus provide valuable data for species protection and habitat management.

As ungulates are the main prey for large carnivores and play critical roles in food webs, their population dynamics, distributions and habitat selection are important for management of grassland ecosystems (Gao et al., 1996; Wang et al., 1997). Impacts of human activity, livestock, and other herbivores on steppes thus represent a global concern (Boyce and McDonald, 1999; Manly et al., 2002). Such knowledge may provide valuable information on ungulate habitat use, life history, and interspecific relationships and biodiversity conservation in grassland ecosystems (Boyce and McDonald, 1999; Manly et al., 2002; Stuart et al., 2004). Environmental modification caused by human and livestock-related disturbance can also alter landscape structure resulting in habitat loss or degeneration (Mace and Waller, 1996). Such disturbances may result in habitat selection shifts of

* Corresponding author. Tel. : +86-13945671746;
Fax : +86-0451-86372718;
E-mail: liubw1@sina.com

ungulates, thereby allowing them to meet foraging and other critical resource requirements (Hernandez and Laundre, 2005). An ungulate's response to disturbance depends on perceived threats and both the potential benefits and costs of the response (West et al., 2002; Beale and Monaghan, 2004). The primary response mechanism may be attributable to the ungulate's perception of a threat from approaching humans or livestock, balanced against the costs incurred in moving to a different habitat (Stillman and Goss-Custard, 2002). If the effect of the disturbance is significant, ungulates may migrate out of the area, ignoring other habitat requirements in order to avoid the disturbance. In contrast, if the cost of moving is greater, they may be more tolerant of disturbance (Yasué, 2006).

As a keystone species on the Asia-European steppe (one of the main herbivores and critical prey for carnivores), Mongolian gazelle (*Procapra gutturosa*) was listed in Category II of the National Protected Wild Animals of China in 1989 (Wang, 2003). They are endemic ungulates and historically were widespread on the Asia-European steppe (Lushchekina et al., 1983). Mongolian gazelles were once widespread in north China with a population of 300,000–500,000 before the 1950s (Gao et al., 1996). Due to poaching, human disturbance, and overgrazing, the number decreased to < 30,000 individuals in 1995 and < 8000 in 2000 with a distribution of less than 75,000 km² in the transboundary area of China, Mongolia, and Russia, which was only 25% of that in the 1950s (Gao et al., 1996; Wang et al., 1997; Jiang et al., 1998; Li et al., 2001; Jin and Ma, 2004; Olson et al., 2005). Given both the reduced population size and limited habitat area, habitat change may drastically shift the habitat selection strategy of the Mongolian gazelle (Lhagvasuren and Milner-Gulland, 1997; Leimgruber et al., 2001; Mueller et al., 2008). Research to date, however, has focused primarily on morphology, taxonomy, reproduction, diet, grazing behavior, population structure, activity rhythm, and diseases (Jiang et al., 1993, 2003; Gao et al., 1995; Olson et al., 2005; Ito et al., 2006; Luo et al., 2008; Liu et al., 2009, 2010). Studies of habitat use by Mongolian gazelle are urgently needed, especially studies of the impacts of human and livestock-related disturbances on its habitat selection, so as to establish a conservation plan for this species and a management strategy for the grassland ecosystem.

As a consequence of human population growth and the development of stockbreeding around Dalai Lake during recent decades, overgrazing and steppe degradation have increased (Jin and Ma, 2004). Grass harvesting in late fall, sympatric livestock grazing, and extremely cold weather with strong winds and deep snow result in severe forage shortages for Mongolian gazelle in winter (Jin and Ma, 2004; Luo et al.,

2008). Obtaining forage and response to disturbance are therefore important factors affecting survival and habitat selection by Mongolian gazelle. Furthermore, since the 1980s, Mongolian gazelle movements have been hindered due to the local government and residents setting fences to mark the boundaries between neighboring pastures and protect fodder sources. To efficiently manage the transboundary areas, human activities and livestock grazing have been forbidden within the regions within 10 km of the border between China and Mongolia except by special permission. As a result, intensities of human and livestock-related disturbances are low in this area. This difference in land use provided us with the opportunity to compare habitat selection strategies under different disturbance intensities.

The goals of this study were: (1) determine the critical factors underlying habitat selection of the gazelles; (2) determine the gazelles' habitat preferences in this area; and, (3) determine how habitat selection varies with disturbance intensity and explore the primary underlying mechanism.

MATERIALS AND METHODS

Ethics statement

The land we accessed includes a protected area and transboundary regions between China and Mongolia. All field studies were permitted by relevant authorities, including the Management Bureau of Dalai Lake National Nature Reserve and the Frontier Force of Hulunbeir. The field studies involved a protected species (Mongolian gazelle, Category II of the National Protected Wild Animals of China). Thus, an animal ethics approval was granted by Animal Ethics Commission of the College of Wildlife Resources, Northeast Forestry University. Our observation and fieldwork were designed so as not to affect the behavioral rhythm and survival of Mongolian gazelle.

Study area

The study area was located around Dalai Lake (47°45'50"–

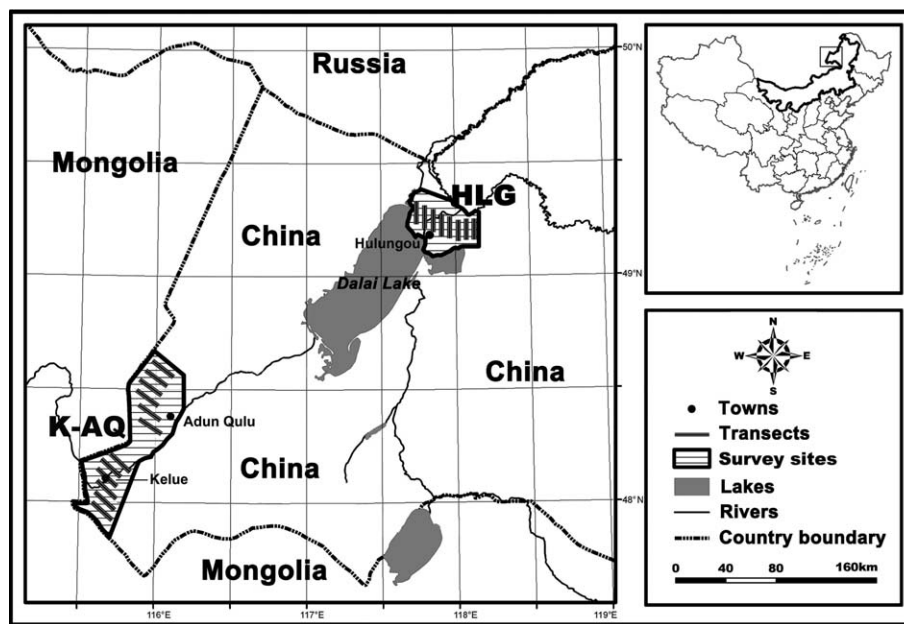


Fig. 1. Study area of habitat selection of Mongolian gazelle around Dalai Lake, Inner-Mongolia, China, in winters of the 2005–2008 period. Gray lines denote the transects we set for surveys. The comparative study was carried out between Kelue-Adun Qulu (K-AQ) and Hulungou (HLG).

49°20'20"N, 115°30'10"–120°30'10"E), Inner-Mongolia, China (Fig. 1). Altitude in this area ranges from 500–800 m. The climate is temperate continental characterized by aridity, wide diurnal, annual and inter-annual temperature variation, and cold winters with strong winds. Annual mean temperature there is 0.4°C with 3100 sunlight hours and a frost-free period of 125–130 days per year. Annual precipitation in this area is 200–350 mm which is concentrated in June to August, and the annual evaporation is 5–6 times greater than input via precipitation (Chronicle of Hulun Lake Compiling Committee,

1998). The area around Dalai Lake contains 653 plant species (Luo et al., 2008). The major vegetation type there is steppe, and desert steppe, semi-desert steppe, and meadow are extensively concomitant in small patches. Vegetation is dominated by *Achnatherum splendens*, *Stipa krylovii*, *Aneurolepidium chinenses*, *Stipa grandis*, *Salsola collina*, *Allium mongolicum*, *Artemisia frigida*, and *Caraganarob stenophylla* (Luo et al., 2008). Three hundred and seventy-two vertebrate species are found in the area, including 30 fishes, one amphibian, three reptiles, 303 birds, and 35 mammals

Table 1. Habitat selection factors recorded in the surveys of Mongolian gazelle around Dalai Lake, Inner-Mongolia, China, in winters in the 2005–2008 period.

Factors (units)	Descriptions
Presence/absence (1/0)	Presence=1, absence=0.
Altitude (m)	We recorded the altitude of the center of each 2 m × 2 m plot using a handheld GPS.
Slope (°)	We extracted the slope of the center of each 2 m × 2 m plot by ESRI ArcGIS 9.2 on 1:50000 DEM of the study area.
Aspect	We extracted the aspect of the center of each 2 m × 2 m plot by ESRI ArcGIS 9.2 on 1:50000 DEM of the study area. We extracted four categories: S67.5°E-S22.5°W, N22.5°E-S67.5°E, S22.5°W-N67.5°W, S67.5°W-N22.5°E.
Slope position	We estimated the position of each center of 2 m × 2 m plot on the slope and recorded three categories: lower, middle, upper.
Wind direction	We estimated the wind direction at the center of 2 m × 2 m plot and recorded nine categories: windless, N, NE, E, SE, S, SW, W, NW.
Wind power	We estimated the wind power at the center of 2 m × 2 m plot and recorded four categories: windless, light, moderate, strong.
Visibility (m)	We measured the maximal viewable distances on eight directions (north (N), northeast (NE), east (E), southeast (SE), south (S), southwest (SW), west (W), northwest (NW)) at 0.8 m height level by laser ranging telescope at the center of 2 m × 2 m plot and calculated the mean value.
Water distance (m)	We extracted the distance from the center of each 2 m × 2 m plot to the nearest open water by ESRI ArcGIS 9.2 on the 1:50000 hydrology vectorgraph.
Ground condition	We estimated the character of land-surface within each 2 m × 2 m plot as four categories: sandy, clayey, muddy, gravelly.
Snow depth (cm)	We measured the snow depths using a steel meter stick on five random points within each 2 m × 2 m plot and calculated the mean value.
Plant height (cm)	We measured the heights of 25 random plant culms within each 2 m × 2 m plot and calculated the mean value.
Vegetation cover (%)	We estimated the percentage of projection of aboveground vegetation cover to the area of each 2 m × 2 m plot.
Vegetation type	We determined vegetation type in each 2 m × 2 m plot by primary plant species. We recorded four categories: <i>Stipa</i> spp., <i>Aneurolepidium chinenses</i> , <i>Stipa</i> spp.+ <i>Aneurolepidium chinenses</i> , Herbage.
Species number (species)	We identified all the plants in each 2 m × 2 m plot and counted the total number of plant species.
Density (culms/m ²)	We established five 0.5 m × 0.5 m subplots at the center and four corners of each 2 m × 2 m plot. We counted plant culm number within each subplot and calculated their mean value to estimate the plant density per 1 m ² .
Aboveground biomass (g/m ²)	We collected aboveground parts of plants in five 0.5 m × 0.4 m subplots at the center and four corners of each 2 m × 2 m plot. We air-dried (60°C) the collections to constant weights and calculated their mean weight to estimate aboveground biomass per 1 m ² .
Road distance (m)	We digitized 1:50000 transportation map of study area and calculated the distance from the center of each 2 m × 2 m plot to the nearest road (including railroad, expressway, state road, provincial highway, county road and grassland road) by ESRI ArcGIS 9.2.
Fence distance (m)	We recorded all the corners of each fence by GPS and mapped a fence digital graph by linking corners in ESRI ArcGIS 9.2. We calculated the distance between the center of each 2 m × 2 m plot and nearest fence.
Settlement distance (m)	We recorded the settlement positions (including towns, villages, houses, wigwams or tents) by GPS. We drew a digital map of settlement and measured the distance from each 2 m × 2 m plot center to nearest settlement by ESRI ArcGIS 9.2.
Human activity distance (m)	We measured distance to the nearest human activity from the center of each 2 m × 2 m plot using a laser ranging telescope.
Livestock distance (m)	We measured distance to the nearest livestock individual from the center of each 2 m × 2 m plot using a laser ranging telescope.

(Chronicle of Hulun Lake Compiling Committee, 1998). Main livestock species around Dalai Lake are domestic sheep (*Ovis aries*), goat (*Capra aegagrus hircus*), cattle (*Bos taurus*), horse (*Equus caballus*), and camel (*Camelus bactrianus*). Livestock and human population were increased to 4 million and 450,000 respectively in this area in 2007, as a consequence of rapid stockbreeding development and human population growth during recent decades (Luo et al., 2008). The main soil types include chestnut soil, dark meadow soil, gray meadows soil, boggy soil, saline soil, alkali soil, and sandy soil (Chronicle of Hulun Lake Compiling Committee, 1998).

We carried out field surveys in Kelue town and Adun Qulu town (K-AQ, 1235.8 km²), located near the national boundary between China and Mongolia, and Hulgou town (HLG, 753.6 km²) near Dalai Lake (Fig. 1), as these two sites were the only strongholds of the Mongolian gazelle population round Dalai Lake (Luo et al., 2008).

Data collection

We located and surveyed 20 transects from December 2005 to March 2006, with a length of 15 km for each transect. Twelve transects (180 km in total length) were placed in the K-AQ area and eight (120 km in total length) in the HLG area (Fig. 1). In each site (K-AQ and HLG), we placed the first transect by randomly selecting the starting point and direction (we generated two random numbers ranging from minimums to maximums of the latitudes and longitudes of the site and used them as the latitude and longitude of the starting point of the first transect; then, we generated another random number ranging from 0 to 360 (°) and used it as the direction (0°-north, 90°-east, 180°-south, 270°-west) of the starting point of the first transect; random number generations were processed in Microsoft Excel). The remaining transects were established at a parallel distance of 10 km from the first transect. We repeated the surveys along these transects once each winter (December to next March) from 2006 to 2008.

We walked along each transect at a speed of 3 km/h and counted the number of individual humans and livestock within 1 km of both sides of these transects using a laser range telescope (Apresys PRO 1500 SPD, Los Angeles, California, USA). We measured 21 vegetation and habitat factors in 2 m × 2 m plots at the transect starting point and at 1 km intervals along the transect (Table 1). While traversing each transect, we recorded presence and the number of Mongolian gazelle herds that were observed within 1 km of both sides of the transect, counted the individuals in each herd, measured the distance of each herd from the transect by the laser range telescope, and recorded its location using a GPS receiver (Garmin eTrex Vista H, Olathe, Kansas, USA). In addition we recorded presence of gazelle using tracks, foraging signs, dung-groups, and bedding sites along transects. When an individual or sign of gazelle was detected, a 2 m × 2 m plot, with the location of the individual or track as the plot center, was set and habitat and vegetation characteristics were recorded. Vegetation and habitat factors were recorded in 1486 plots (929 in K-AQ and 557 in HLG).

Statistical analyses

We analyzed the data from the K-AQ and HLG areas separately using similar statistical methods in SPSS 13.0 software, and considered the data across years as independent. We

calculated densities of human and livestock for each transect (density = recorded number of individuals/(2 km × 15 km)), and used them as indicators of disturbance intensities. We used Kolmogorov-Smirnov (K-S) tests to check their normality and the data in both K-AQ (K-S test $P = 0.64$) and HLG (K-S test $P = 0.59$) areas were normally distributed. We, thus, used independent samples t -tests to detect any differences in disturbance densities between these two areas.

Taking plots as the sampling units, we calculated Moran's I values for the raw data of the habitat variables for twenty distance classes (100 m, 200 m, ..., 1900 m, 2000 m) in the software package SAM (Rangel et al., 2006), to assess the effect of spatial autocorrelation. As Moran's I values for all the variables were between -0.2 and 0.2 at distance classes of > 400 m, we excluded the plots with distances of < 400 m from other plots in the subsequent analyses. In total, 779 plots in K-AQ and 416 plots in HLG were included in the following analyses. We used K-S tests to check normality of all the variables. If any variable were non-normal (K-S test $P < 0.05$), we made \ln -transformations (see Results). We, then, used independent samples t -tests to test for differences in habitat parameters between K-AQ and HLG areas. In order to reduce the interaction between variables, we calculated pairwise Pearson's correlation coefficients between all variables. If any coefficient was > 0.70 , we removed the variable with higher deviation within this variable pair (see Results).

An information theory approach was used to establish best-fit habitat selection models for Mongolian gazelles. We used Akaike's information criterion (AIC) to compare candidate models and ranked them by ΔAIC_c (Burnham and Anderson, 2002). Relative likelihood of each model was assessed by Akaike weights (AIC_w). We then chose the models with the ΔAIC_c values of < 2 as competing habitat selection models (Burnham and Anderson, 2002). To assess contributions of the factors to habitat selection of gazelles, we followed Manly et al. (2002) to build binary-logistic regression formulas between presence/absence of the gazelles and habitat variables,

Table 2. Results of independent samples t -tests of the ecological factors affecting habitat selection of Mongolian gazelle between K-AQ and HLG areas around Dalai Lake, Inner-Mongolia, China, in winters in the 2005–2008 period.

	K-AQ ($n = 609$)		HLG ($n = 297$)		F^*	P^{**}
	Mean	SE	Mean	SE		
Altitude (m)	635.711	83.304	573.971	65.814	432.230	0.070
Slope (°)	7.084	12.505	5.762	11.545	2.821	0.499
\ln Aspect	1.467	0.941	1.725	0.463	0.652	0.125
\ln Slope position	0.698	0.332	0.666	0.317	0.717	0.527
\ln Wind direction	1.500	0.121	1.410	0.414	0.632	0.423
\ln Wind power	1.124	0.374	1.080	0.430	0.593	0.608
Visibility (m)	1580.750	312.977	1451.424	448.591	1203.621	0.046
Water distance (m)	2159.657	731.877	1809.583	1406.134	586.690	0.000
\ln Ground condition	1.031	0.153	0.914	1.201	0.204	0.080
Snow depth (cm)	10.815	1.412	10.455	1.856	2.222	0.321
\ln Plant height (cm)	35.267	0.712	21.234	0.587	11.571	0.000
Vegetation cover (%)	60.520	20.101	44.321	18.257	7.554	0.023
\ln Vegetation type	0.431	0.607	0.852	0.647	0.213	0.000
Species number (species)	3.989	1.646	3.482	1.691	0.984	0.218
Density (culms/m ²)	106.004	31.321	79.004	28.878	23.349	0.000
Aboveground biomass (g/m ²)	76.524	24.575	44.377	18.221	19.317	0.011
Road distance (m)	2419.211	1251.023	1806.571	1316.652	596.778	0.038
Fence distance (m)	2483.331	1057.211	1360.442	1332.113	1365.257	0.002
Settlement distance (m)	2577.634	1427.915	1702.187	802.248	968.801	0.000
Human activity distance (m)	2421.490	2389.821	1925.635	1287.047	268.383	0.000
Livestock distance (m)	1584.214	1979.305	945.514	1088.757	1026.522	0.000

Note: *, F value for independent samples t -test; **, P value for independent samples t -test.

and ranked the variables by their explanatory power (R^2).

To analyze the gazelle's preference relative to each habitat factor and to explain the response of Mongolian gazelle to human and livestock disturbance in winter, we classified the factors based on their means and maximum-minimum variations and calculated habitat selection function (E) of each factor class (Boyce and McDonald, 1999; Li et al., 2001; Boyce et al., 2002; Manly et al., 2002). The

model in Boyce and McDonald (1999) was used in this study. Habitat selection function ranges from -1 to 1 , with values of > 0.1 , < -0.1 , and -0.1 – 0.1 indicative of preference, avoidance, and random selection of a habitat resource, respectively. We did not calculate habitat selection functions for the factors that were excluded according to the Pearson's correlation analyses. Furthermore, we compared the habitat selection functions and the explanatory pow-

Table 3. Pairwise Pearson's correlation coefficients of the ecological factors of habitat selection of Mongolian gazelle in K-AQ (under the diagonal) and HLG (above the diagonal) areas around Dalai Lake, Inner-Mongolia, China, in winters in the 2005–2008 period.

	Altitude	Slope*	In Aspect*	In Slope position	In Wind direction*	In Wind power*	Visibility	Water distance	In Ground condition*	Snow depth	In Plant height
Altitude	–	0.444	0.437	0.329	0.101	0.332	0.439	–0.002	0.332	–0.443	0.003
Slope	0.362	–	0.112	0.356	0.112	0.301	–0.549	0.001	0.258	–0.779	0.239
In Aspect	0.443	–0.021	–	0.702	0.221	–0.128	–0.443	–0.291	0.009	0.281	–0.415
In Slope position#	0.617	0.122	–0.043	–	0.815	0.777	0.444	–0.001	0.666	–0.561	–0.101
In Wind direction#	–0.023	0.233	0.674	–0.231	–	0.320	0.107	–0.219	–0.551	–0.005	0.129
In Wind power#	0.542	0.200	0.012	0.634	0.023	–	0.333	–0.198	0.559	–0.541	0.009
Visibility	0.594	–0.431	–0.179	0.436	0.111	0.221	–	0.449	0.449	–0.444	–0.210
Water distance	0.104	–0.005	–0.143	0.098	0.002	–0.101	0.217	–	0.014	0.100	0.627
In Ground condition	0.472	0.103	–0.009	0.788	–0.726	0.810	0.443	0.327	–	–0.388	–0.298
Snow depth	–0.219	–0.225	0.348	–0.442	–0.168	–0.543	–0.334	0.098	–0.328	–	0.605
In Plant height	0.003	0.122	–0.219	0.088	–0.003	0.112	–0.101	0.554	–0.349	0.541	–
Vegetation cover	0.111	–0.219	0.008	0.446	0.228	–0.453	0.107	0.549	0.337	–0.287	0.214
In Vegetation type	0.178	–0.177	0.082	0.191	–0.002	0.211	0.243	0.443	0.235	–0.333	–0.256
Species number	0.156	–0.111	0.092	–0.017	0.339	–0.005	0.159	–0.337	0.101	0.431	–0.049
Density#	–0.126	–0.100	0.093	–0.142	0.005	–0.010	–0.228	–0.444	–0.232	0.214	0.439
Aboveground biomass	–0.105	0.194	–0.008	–0.102	0.002	0.001	0.313	–0.559	–0.253	0.491	0.666
Road distance#	0.122	–0.048	–0.111	0.422	0.001	–0.231	–0.318	0.032	0.102	–0.257	–0.223
Fence distance	0.008	–0.045	–0.223	0.332	–0.002	0.029	–0.125	–0.120	–0.111	–0.337	–0.446
Settlement distance#	0.324	0.257	–0.084	0.239	–0.005	0.229	–0.101	0.384	0.135	–0.143	0.358
Human activity distance	0.104	–0.254	0.003	–0.104	0.001	–0.268	–0.328	0.253	0.003	0.278	–0.516
Livestock distance#	0.009	0.004	–0.123	–0.238	0.157	–0.033	–0.332	0.653	–0.346	0.429	–0.542

	Vegetation cover	In Vegetation type	Species number	Density*	Aboveground biomass	Road distance*	Fence distance*	Settlement distance	Human activity distance	Livestock distance
Altitude	0.201	0.089	0.232	–0.221	0.001	0.325	0.002	0.459	0.100	0.002
Slope	–0.431	–0.239	–0.004	0.112	0.239	0.002	0.005	0.491	–0.419	0.120
In Aspect	–0.003	0.088	–0.001	0.128	–0.192	–0.204	–0.443	0.012	0.003	–0.362
In Slope position#	0.554	0.219	–0.001	–0.328	–0.009	0.521	0.306	0.119	0.201	0.198
In Wind direction#	0.309	0.104	0.222	–0.014	–0.001	0.001	–0.136	0.110	–0.005	0.431
In Wind power#	–0.326	0.117	0.012	0.104	–0.007	–0.124	–0.019	0.387	–0.198	0.141
Visibility	0.224	0.198	0.201	–0.111	0.428	–0.198	0.015	–0.225	–0.247	–0.458
Water distance	0.672	0.541	–0.299	–0.581	–0.610	–0.001	–0.098	0.115	0.391	0.549
In Ground condition	0.551	0.881	0.007	–0.194	–0.315	–0.018	–0.281	0.281	–0.112	–0.418
Snow depth	–0.299	–0.419	0.501	0.213	0.385	–0.332	–0.224	–0.148	0.391	0.376
In Plant height	0.319	–0.264	–0.111	0.394	0.516	–0.116	–0.410	0.351	–0.559	–0.613
Vegetation cover	–	–0.332	0.611	0.661	–0.444	–0.431	0.515	–0.005	0.004	–0.347
In Vegetation type	–0.415	–	0.338	–0.337	–0.614	–0.583	0.317	0.004	–0.127	0.271
Species number	0.629	0.258	–	0.668	0.102	–0.099	–0.513	–0.217	–0.301	–0.117
Density#	0.910	–0.294	0.793	–	0.917	–0.210	–0.581	0.331	–0.384	–0.661
Aboveground biomass	–0.549	–0.639	–0.118	0.912	–	0.782	–0.351	–0.398	–0.312	–0.610
Road distance#	–0.495	–0.687	–0.234	–0.120	–0.099	–	0.666	0.661	0.416	–0.519
Fence distance	0.463	0.398	–0.442	–0.432	–0.323	0.727	–	0.732	0.881	0.719
Settlement distance#	0.114	–0.121	–0.216	0.383	–0.486	0.669	0.885	–	0.599	0.671
Human activity distance	–0.010	–0.005	–0.180	–0.329	–0.222	0.495	0.669	0.694	–	0.601
Livestock distance#	–0.259	0.328	–0.254	–0.553	–0.587	–0.491	0.216	0.811	0.517	–

Note: #, variables excluded in the analyses of habitat selection of Mongolian gazelles in the K-AQ area; *, variables excluded in the analyses of habitat selection of Mongolian gazelles in the HLG area.

Table 4. Candidate models, $\Delta AICc$ s and $AICw$ s of habitat selection of Mongolian gazelle in K-AQ and HLG areas around Dalai Lake, Inner-Mongolia, China, in winters in the 2005–2008 period.

Models		K^a	$\Delta AICc$	$AICw$
K-AQ area				
1*	Snow depth+biomass+cover+visibility+fence distance+ln ground condition+ln vegetation type+human activity distance+slope+water distance+ln aspect	11	0.000	0.559
2	Snow depth+biomass+cover+visibility+fence distance+ln ground condition+ln vegetation type+human activity distance+slope+water distance+species number+ln aspect	12	2.285	0.178
HLG area				
1*	Snow depth+biomass+ln plant height+ln slope position+visibility+water distance+settlement distance+human activity distance+ln vegetation type+species number+cover	11	0.000	0.623
2	Snow depth+biomass+ln plant height+ln slope position+visibility+water distance+settlement distance+human activity distance+ln vegetation type+altitude+species number+cover+livestock distance	13	2.096	0.199

Note: ^a, variable number in the model; *, best-fit model.

ers of the ecological factors between K-AQ and HLG to detect differences in habitat selection strategies.

RESULTS

We recorded 522 individuals (306 in K-AQ and 216 in HLG) belonging to 66 herds (44 in K-AQ and 22 in HLG) and 499 tracks (316 in K-AQ and 183 in HLG) of Mongolian gazelles in the winters of 2005–2008. The average group size was 6.95 ± 1.05 individuals in the K-AQ area, with a mean sex ratio of male:female = 0.47 ± 0.22 and 0.58 ± 0.61 fawns in each group. While, in the HLG site, the average group size was 9.82 ± 2.36 individuals, and the mean sex ratio (male:female) and fawn numbers were 0.39 ± 0.21 and 0.79 ± 0.53 for each group. Human and livestock densities were significantly greater ($P = 0.010$) within HLG (3.591 ± 1.674 individuals/km² and 27.007 ± 16.095 individuals/km²) than that in K-AQ (0.434 ± 0.017 individuals/km² and 3.021 ± 0.211 individuals/km²).

Aspect, slope position, wind direction, wind power, ground condition, plant height, and vegetation type were non-normally distributed (K-S test P values were < 0.05) and ln-transformed (Table 2). The results of independent samples t -tests showed no significant differences of altitude ($P = 0.070$), slope ($P = 0.499$), ln aspect ($P = 0.125$), ln slope position ($P = 0.527$), ln wind direction ($P = 0.423$), ln wind power ($P = 0.608$), ln ground condition ($P = 0.080$), snow depth ($P = 0.321$), and species number ($P = 0.218$) between K-AQ and HLG (Table 2). Visibility ($P = 0.046$), water distance ($P = 0.000$), ln plant height ($P = 0.000$), vegetation cover ($P = 0.023$), ln vegetation type ($P = 0.000$), density ($P = 0.000$), aboveground biomass ($P = 0.011$), road distance ($P = 0.038$), fence distance ($P = 0.002$), settlement distance ($P = 0.000$), human activity distance ($P = 0.000$), and livestock distance ($P = 0.000$) showed significant differences between these two areas (Table 2). Based on Pearson's correlation analyses, we excluded density, wind direction, wind power, slope position, settlement distance, road distance, and livestock distance in latter analyses of K-AQ data (Tables 2 and 3). Similarly, density, wind direction, wind power, aspect, slope, road distance, fence distance, and ground condition were excluded for HLG (Tables 2, 3).

The K-AQ area modeling exercise resulted in one model with $\Delta AICc < 2.000$ (Table 4). This best-fit model ($\Delta AICc = 0.000$, $AICw = 0.559$, $R^2 = 0.987$) included 11 habitat factors

Table 5. Results of binary-logistic regressions of the best-fit models of habitat selection of Mongolian gazelle in K-AQ and HLG areas around Dalai Lake, Inner-Mongolia, China, in winters in the 2005–2008 period.

Variables	Standard coefficient (r)	t	P	R^2
K-AQ area: $F_{11, 768} = 136.025$, $R^2 = 0.987$, $P < 0.010$				
Snow depth	-0.851	-3.107	< 0.010	0.352
Biomass	0.714	10.295	< 0.010	0.297
Slope	0.676	7.018	< 0.010	0.107
Fence distance	0.616	6.660	< 0.010	0.102
ln Ground condition	0.567	21.259	< 0.010	0.067
Human activity distance	0.205	4.779	< 0.010	0.040
Visibility	0.180	3.890	< 0.010	0.006
Water distance	0.159	-4.709	< 0.010	0.006
ln Vegetation type	-0.135	-4.442	< 0.010	0.006
ln Aspect	-0.124	-2.764	< 0.010	0.003
Cover	0.045	1.334	0.031	0.001
HLG area: $F_{11, 405} = 186.326$, $R^2 = 0.984$, $P < 0.010$				
Biomass	0.879	9.333	< 0.010	0.401
Snow depth	-0.675	10.032	< 0.010	0.315
ln Slope position	-0.336	-7.717	< 0.010	0.101
Species number	0.179	5.320	< 0.010	0.052
Cover	0.169	-4.703	< 0.010	0.041
Visibility	-0.159	-3.875	< 0.010	0.030
Water distance	0.118	2.796	< 0.010	0.020
ln Vegetation type	0.087	2.753	< 0.010	0.012
ln Plant height	0.081	2.459	0.014	0.007
Settlement distance	0.051	1.551	0.022	0.004
Human activity distance	0.006	-0.179	0.048	0.001

(Tables 4 and 5). According to the binary-logistic regression, snow depth ($r = -0.851$, $P < 0.010$, $R^2 = 0.352$), aboveground biomass ($r = 0.714$, $P < 0.010$, $R^2 = 0.297$), slope ($r = 0.676$, $P < 0.010$, $R^2 = 0.107$), and fence distance ($r = 0.616$, $P < 0.010$, $R^2 = 0.102$) affected gazelle presence ($R^2 > 0.100$, Table 5). Other factors had R^2 values of < 0.100 (Table 5). Habitat selection functions indicated that Mongolian gazelle preferred shallow snow (< 5 cm, $E = 0.662$) and greater aboveground biomass (50–75 g/m², $E = 0.641$; 75–100 g/m², $E = 0.900$; > 100 g/m², $E = 0.982$), and selected habitat far from human activity (500–2000 m, $E = 0.193$; > 2000 m, $E =$

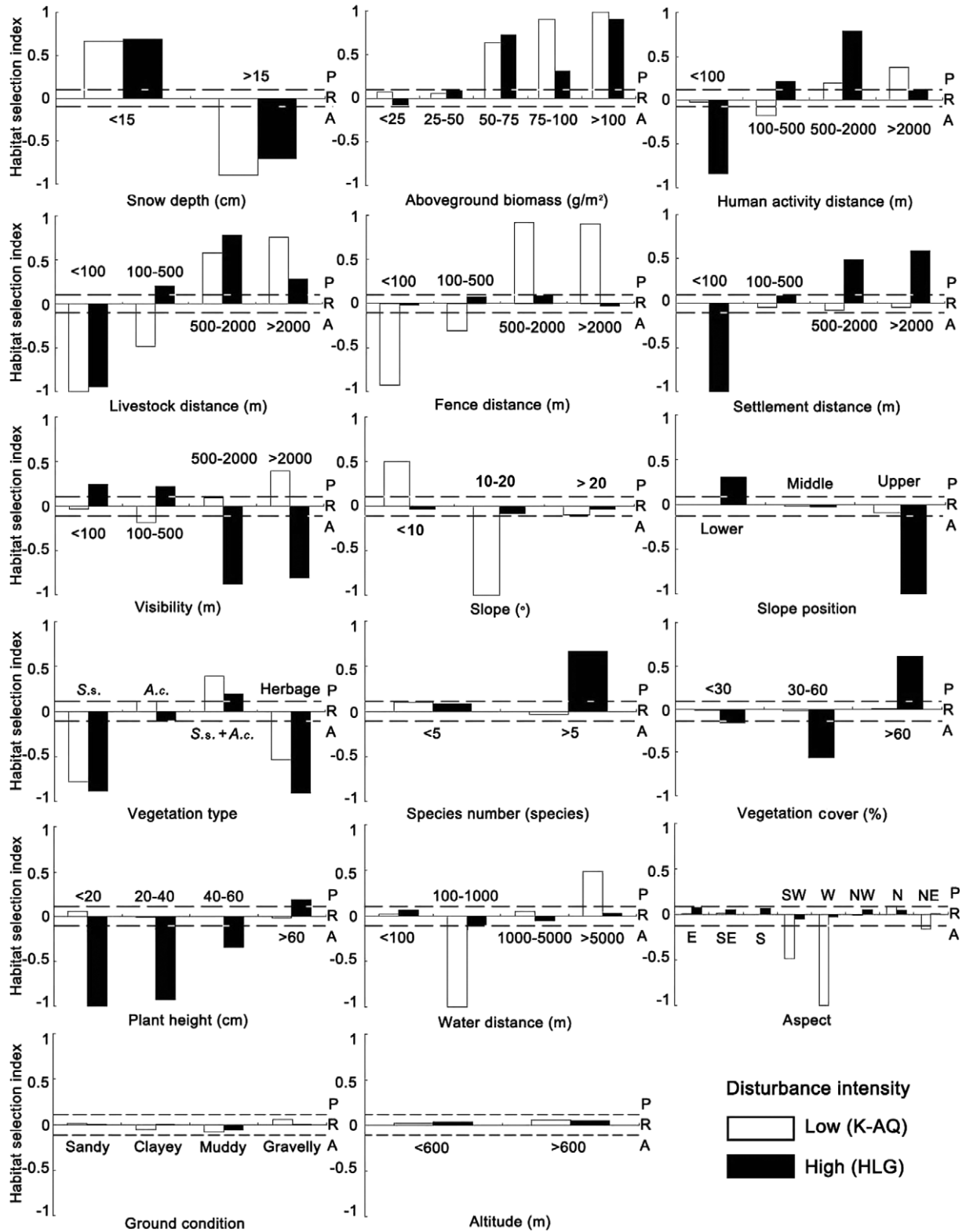


Fig. 2. Habitat selection functions of each habitat class of Mongolian gazelle under different human and livestock disturbance intensities (K-AQ and HLG) around Dalai Lake, Inner-Mongolia, China, in winters in the 2005–2008 period. Broken lines denote habitat selection function dividing values of ± 0.1 . Bars between two broken lines (-0.1 – 0.1), above the upper broken line (> 0.1) and below the lower broken line (< -0.1) respectively indicate random selection (R), preferring (P) and avoidance (A). In the histogram of vegetation type, S.s. = *Stipa* spp., A.c. = *Aneurolepidium chinenses*, S.s.+A.c. = *Stipa* spp.+*Aneurolepidium chinenses*. In the histogram of aspect, N = north, NE = northeast, E = east, SE = southeast, S = south, SW = southwest, W = west, NW = northwest.

0.371), livestock (500–2000 m, $E = 0.578$; > 2000 m, $E = 0.758$) and fence (500–2000 m, $E = 0.920$; > 2000 m, $E = 0.900$). Wider visibility (> 2000 m, $E = 0.395$), low slope terrain (< 10°, $E = 0.500$), vegetation type of *Aneurolepidium chinenses* ($E = 0.122$), *Stipa* spp.+*Aneurolepidium chinenses* ($E = 0.394$) and long open water distance (> 5000 m, $E = 0.486$) were used in the near boundary areas. Other factor classes had habitat selection functions of -0.1 to 0.1 , indicating random selection (Fig. 2).

For the HLG area, one model achieved $\Delta AICc < 2.000$ (Table 4), and 11 factors were included in this best-fit model ($\Delta AICc = 0.000$, $AICw = 0.623$, $R^2 = 0.984$) (Tables 4, 5). Aboveground biomass ($r = 0.879$, $P < 0.010$, $R^2 = 0.401$), snow depth ($r = -0.675$, $P < 0.010$, $R^2 = 0.315$), and ln slope position ($r = -0.336$, $P < 0.010$, $R^2 = 0.101$) had R^2 values > 0.100 (Table 5). Other factors achieved R^2 values of < 0.100 (Table 5). Snow depth, ln slope position, and visibility were negatively correlated with the presence of Mongolian gazelle (Table 5). The gazelles preferred shallow snow cover (< 15 cm, $E = 0.687$) and greater aboveground biomass (50–75 g/m², $E = 0.731$; 75–100 g/m², $E = 0.310$; > 100 g/m², $E = 0.910$). They avoided human activity (100–500 m, $E = 0.210$; 500–2000 m, $E = 0.781$; > 2000 m, $E = 0.109$), livestock (100–500 m, $E = 0.208$; 500–2000 m, $E = 0.781$; > 2000 m, $E = 0.283$), and settlement (500–2000 m, $E = 0.490$; > 2000 m, $E = 0.588$). Reduced visibility (< 100 m, $E = 0.242$; 100–500 m, $E = 0.211$), lower slope position ($E = 0.311$), *Stipa* spp.+*Aneurolepidium chinenses* ($E = 0.205$) vegetation type, greater vegetation species richness (> 5 species, $E = 0.661$), higher cover (> 60%, $E = 0.609$), and larger plant height (> 60 cm, $E = 0.190$) were selected in this area. However, we found only random selection for other factor classes, based upon habitat selection functions falling between -0.1 and 0.1 (Fig. 2).

DISCUSSION

The factor selection procedure excluded parameters relating to wind and vegetation density from analyses of data from both the K-AQ and HLG areas due to their high correlations with other ecological variables. Although both topographic and demographic conditions contributed to variable selection, the best-fit habitat selection models included discrepant variables between the two sites. Slope, aspect and ground condition were excluded for the HLG model, and slope position was rejected by the K-AQ model, as these parameters represent different topographic characteristics and habitat variation between the two sites that promote different relationships between the sites themselves and other environmental parameters. Distances to the nearest road and fence were excluded in the HLG model and settlement and livestock distances were rejected by the K-AQ model as they exert different kinds of demographic effects and conditions are not homogeneous between these two areas.

Snow cover and aboveground biomass

The results indicated that snow depth and aboveground biomass were limiting factors for habitat selection of Mongolian gazelle in both K-AQ and HLG in winter, as they explained 30–40% of the variation for the models for those sites. The gazelles preferred lighter snow cover and higher aboveground biomass. Snow cover is essential for habitat

selection of wild animals in winter (Sweeney and Sweeney, 1984). Increasing snow depth has a significant negative effect on food supply by covering nutritious evergreen forbs or half-shrubs, forcing ungulates to consume greater quantities of taller grasses and woody browse with lower nutrition, and increasing energy costs of movement, digging in the snow to obtain forage, or avoidance of predators and disturbance (Parker et al., 1999; Doerr et al., 2005). These phenomena have been reported for Dall's sheep (*Ovis dalli*), elk (*Cervus elaphus*), mule deer (*Odocoileus hemionus*), and white-tailed deer (*Odocoileus virginianus*), suggesting that snow cover is critical for ungulate habitat selection in winter (Rachlow and Bowyer, 1998; Poole and Mowat, 2005). Our results are consistent with those of previous studies in that Mongolian gazelle selected shallow snow depth (< 15 cm) and rarely used deeper snow habitat to reduce energy cost and get enough food (Doerr et al., 2005).

As the only source of forage, aboveground biomass is another limiting factor impinging upon survival and habitat selection by ungulates (Poole and Mowat, 2005). Our results implied that Mongolian gazelles preferred habitat with abundant forage in both K-AQ and HLG, which is consistent with findings from research on Mongolian gazelle in the eastern Mongolian steppe by Leimgruber et al. (2001), Ito et al. (2006), and Mueller et al. (2008). However, Jin and Ma (2004) indicated that forage abundance is a secondary factor in habitat selection by Mongolian gazelle in spring when medium and lower aboveground biomass were preferred. We considered this difference a result of inter-seasonal trade-offs. Because of starvation and severe body weight loss in winter, optimizing foraging is critical to survival and ungulates may neglect requirements related to other factors. By contrast, when forage availability improves in spring, the importance of forage abundance is reduced and other factors receive increased emphasis (Dumont et al., 2000). Similar phenomena have been reported in Przewalski's gazelle (*Procapra przewalskii*), Przewalski's horse (*Equus przewalskii*) and oribi (*Ourebia ourebi*) (Liu and Jiang, 2002; Pereladova et al., 2002; Mduma and Sinclair, 2008).

Human activity and livestock grazing

Our results support conclusions reported in previous studies that there is a threshold of 0.5 km to 5 km from human and livestock disturbances for normal ungulate activity (Mahoney and Schaefer, 2002; Frid, 2003). Comparison of habitat selection strategies between K-AQ and HLG indicated that Mongolian gazelle respond differently to different intensities of human activity and livestock grazing disturbances. Disturbance had a more significant impact on gazelle activity in the K-AQ area, while gazelles used habitat < 500 m from disturbance in the HLG area. This suggests that there might be a trade-off between perceived threat associated with disturbance and costs of moving out of an area. In the HLG area, greater densities of human/livestock may reduce the opportunity for Mongolian gazelles to be distant from these disturbances. High costs in searching for and moving into habitats that are distant to such disturbances might make the gazelles more tolerant to human/livestock activities. In contrast, human activity and livestock grazing are restricted in the K-AQ area, thus, there might be

increased availability of forage for gazelles, along with fewer disturbances to potentially interfere with movement. In this area, avoiding disturbance may serve as the primary mechanism underlying habitat selection by Mongolian gazelle. Such behavioral responses have also been reported for elk, mule deer, and white-tailed deer (*Odocoileus virginianus*) (Pauley et al., 1993; Parker et al., 1999; Doerr et al., 2005).

Similar responses to the nearest fence were also indicated in winter habitat selection of Mongolian gazelles: as livestock population and grassland grazing intensity is much higher in the HLG area than that in the K-AQ area, local people established more fences in order to manage their pastures and divided the grassland into many small patches. Thus, greater fence density in the HLG area results in a much lower availability of habitat far from fence, and the gazelles are more tolerant to fence disturbance, generating random selection for this ecological parameter. The opposite condition was indicated in the HLG area: due to the lower fence density in this site, gazelles are more sensitive to fence disturbance and thus prefer habitat distant to fence and avoid habitat close to fence disturbance. A reversed pattern of selection on settlement disturbance was implied by our results: in the HLG area, as most of the settlements are permanent houses and sheepfolds, Mongolian gazelles avoid the severe disturbance from them and prefer distant habitat from the settlements. However, because of the controlling of the trans-boundary areas by the army and local government, settlements in the K-AQ area are usually temporary tents. The gazelles may acclimate to this kind of disturbance with low intensity and show random selection on this ecological variable.

Visibility

Selection based upon visibility could be considered an important variable allowing animals to evaluate disturbance and predation risk. Research on elk and mule deer reveals that disturbance intensity and predation risk are lower with decreased visibility (i.e., in covered habitats) (Altendorf et al., 2001; White and Berger, 2001; Dussault et al., 2005), which may be related to difficulties of humans and predators in recognizing animals under conditions where visibility is constrained (Dussault et al., 2005). Predators of Mongolian gazelles in the Dalai Lake area include wolf (*Canis lupus*), red fox (*Vulpes vulpes*), golden eagle (*Aquila chrysaetos*), steppe eagle (*Aquila nipalensis*), upland buzzard (*Buteo hemilasius*), and, especially, humans (illegal hunting). In the current study, as higher human and livestock disturbance intensities might mean higher predation risk by human, the gazelles preferred reduced viewable range habitat (< 500 m) in the HLG area and selected > 2000 m maximum viewable distance sites in the K-AQ area. This difference suggests that gazelles prefer covered habitats under high disturbance intensity, perhaps as a mean of avoiding disturbance or seeking cover and thereby reducing their risk of predation while simultaneously obtaining more browsing and resting time. In contrast, they selected open habitat and high forage quality under low human and livestock disturbance intensities, despite the risk that the threat of disturbance and predation may increase. We considered our finding to be a reflection of a trade-off between avoidance of disturbance/predation and foraging (Dussault et al., 2005). Animals

should pursue the most important limiting factor foremost while the influence of less important factors should contribute only secondarily (Dussault et al., 2005). As avoiding disturbance/predation is critical for survival under high disturbance intensity (HLG area), gazelles first select covered habitat and ignore other habitat factors. When disturbance intensity declines (in K-AQ area), however, gazelles could select open habitats with higher food availability so as to enhance forage intake, which is the most important limiting factor in this area.

Topography

Our results indicated that Mongolian gazelle selected topographical characteristics more strictly in the K-AQ area compared to the HLG area. They clearly preferred gentle slope (< 10°) and strongly avoided steep topography (10°–20°) in the K-AQ area, while they randomly selected slope in the HLG area. As no significant difference of topographical variables between the two sites could be detected (independent samples *t*-tests of altitude, slope, aspect, slope position, and ground condition were $P > 0.05$). This finding is likely to represent a trade-off between requirements for forage and topographical factors. Frequent human and livestock disturbance and serious competition for forage between gazelles and domestic ungulates in the HLG area likely prompted gazelle to focus on the fulfillment of their foraging demands at the expense of taking other factors into account. For the K-AQ area, however, selection was more strongly influenced by topography, as forage supply was relatively abundant. Similar findings have been reported from studies of habitat use by elk, red deer (*Alces alces*), mule deer, and caribou (*Rangifer tarandus*) (Rettie and Messier, 2000; Kie et al., 2002; Boyce et al., 2003; Dussault et al., 2005).

Management implications

Habitat management is essential for conservation of Mongolian gazelle. Higher forage availability and lighter snow cover are critical for the survival of Mongolian gazelle around Dalai Lake in winter (Gao et al., 1995; Dumont et al., 2000; Jin and Ma, 2004; Doerr et al., 2005; Poole and Mowat, 2005). Thus, artificial snow clearing and provision of supplementary forage will presumably be valuable approaches for its population management. As human disturbance and livestock grazing intensity increased, Mongolian gazelle showed greater resilience to disturbance and used habitat with reduced distances to disturbance sites. Under lower disturbance pressure, Mongolian gazelle preferred more open habitats and gentler slope than under higher disturbance intensity. The differences in habitat selection strategies indicated that, in the K-AQ area, human and livestock population controls need to be continued and that human activity and domestic ungulate grazing restrictions need to be enforced. In the HLG area, we suggest that control of the livestock population, along with conservation education for members of the local communities, establishment, enforcement and execution of effective grassland utilization policies, logical pasture household responsibility and livestock grazing system foundation are imperative for conservation of Mongolian gazelle. These measurements need to be developed based on further detailed habitat research on Mongolian gazelle.

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